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Reduction of Standby Energy Use in Set-top Boxes in the United States and the European Union

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Preface

This report is the Master's Thesis of my Master of Science in Mechanical Engineering at The Lund Institute of Technology, Department of Heat and Power Engineering, Lund, Sweden. This research has been performed at Lawrence Berkeley National Laboratory, Berkeley, California, USA, during the academic year 1999/2000 under supervision of Dr. Alan Meier. Supervisor in Sweden has been Assoc. Prof. Jurek Pyrko.

Many persons have been of great help and have contributed with information to make this report possible. I would like to thank Dr. Alan Meier for having me as a guest at Lawrence Berkeley National Laboratory. Even though he is a very busy man, he was never too busy to help me and discuss my work. I would also like to thank Karen Rosen at Lawrence Berkeley National Laboratory who has contributed with information and helped me in a very significant way. Without these two there would have been no report.

Apart for the above mentioned people I would like to thank all others who have helped me.

Lund, May 2000

Stefan Zandelin

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1 Introduction

An increasing number of electrical products in our homes cannot be switched completely off without unplugging the devices. That means that these products consume electricity 24 hours a day, 7 days a week, often without the consumer knowing about it. This power consumption is called standby power. In some literature standby power is also called leaking electricity, but in this report standby power is used.

Standby power can be as high as 15 or 20 watts in inefficient designs. For just one appliance this is not much, but if the standby power from all the appliances in the world were added up, the amount of power would be substantial. Nobody knows exactly the magnitude of this standby power but estimates have been done for some countries. The International Energy Agency (IEA) is currently working on an estimate that covers all OECD countries. Researchers at Lawrence Berkeley National Laboratory (LBNL) in California USA estimate that 5-10% of the residential electricity use worldwide is standby power. They also estimate that in the U.S., the standby fraction of residential electricity use is 5%. This corresponds to 45 TWh every year [1]. The appliances in Swedish homes are estimated to consume 500 GWh every year in standby mode. That is enough electricity to heat 20,000 Swedish houses [2]. Since these numbers typically are based on few measurements the actual values could easily be much larger or smaller

This paper investigates standby power in set-top boxes. Set-top boxes are sophisticated home communications terminals used to convert or descramble signals for viewing on a television set. Included in the category of "set-top boxes" are cable boxes, satellite receivers, digital terrestrial receivers, signal format converters, and Internet terminals. Recent measurements demonstrate that each box consumes between 10 and 25 watts while switched "off," and about the same as when switched "on." Based on these numbers, LBNL estimates that set-top boxes in the U.S. currently consume about five TWh per year. According to industry projections, this number is likely to grow considerably in the near future. One reason for this growth is that new set-top boxes have more functions and use more power than existing set-tops. Another reason for increased energy use is that the number of set-tops in the homes is expected to grow considerably. In fact, there is some chance that all 250 million TVs in the U.S. will eventually be accompanied by at least one set-top box. Thus, the energy implications of set-top boxes are staggering. With relatively modest changes in the designs of these boxes, researchers at LBNL believe that the standby power demand can be reduced to less than 1 watt.

1.1 Scope of This Study

The definition of standby mode and standby power depends on the product being analyzed. For set-top boxes the Environmental Protection Agency (EPA) use the following definition: "The lowest power state that the set-top box product model enters while connected to a power source. In this mode, the product appears to be off to the user, but may be capable of responding to a signal (e.g., a signal sent from a head end or data provider) and may continue to perform some functions (e.g., remote control sensing and time readout)" [3]. In this report, the following definition of standby is used: "The unit is plugged in and the power switch is in the "off" position".

This study investigates standby power in set-top boxes in the USA, the EU, and Sweden. Some of the questions this study is trying to answer are the following:

- How many set-top boxes exist, and how much are they used?
- How much energy do set-top boxes use in standby mode?
- What proportion of total set-top energy use is used during standby mode?
- Where does the standby power go?
- What can be done to lower standby power?

1.2 Methods

To get an understanding of the growing problem with standby power, a literature study in the area was first carried out. After that a literature study was carried out to get an understanding on how set-top boxes work and where and how they are used. When the literature studies were done it was time to collect data on power levels, stock, and usage patterns of set-top boxes. Most data was collected from earlier studies, but some measurements were performed at Lawrence Berkeley National Laboratory, where the work with this report has been performed. The final step was to calculate energy and power consumption and put the results together.

1.3 Limitations of This Study

No effort has been made to ensure that the measured and collected data are representative of U.S. and EU stock. Most of the products measured and included in this study are new products. The energy use could be underestimated because of older, and less efficient, units are still being used. Also, regional models have not been considered, which may have affected average power estimates.

Data have only been collected and considered for standby and active mode. In some products more modes exist.

Since the use and models of set-top boxes are expected to change dramatically over the coming years, the results are only useful for 1999. This is discussed in section 7.3.

Power measurements on satellite receivers in the U.S. were not taken while connected to the satellite dish. Added power use due to the satellite LNB[1] are estimated based on actual measurements on an LNB connected to Echostar Dishplayer.

[1] Low Noise Block is the name for the device, which is located in the focal point of the dish. It is required to receive, amplify and downconvert the satellite signals.

2 Background

2.1 Previous Standby Power Research

U.S.

The majority of standby power research in the U.S. has been conducted at Lawrence Berkeley National Laboratory (LBNL). The first standby power report to come out of LBNL estimated that 5% of U.S. residential electricity use was due to standby [1]. Later reports included expanded sets of measurements and advice on reducing standby power use.

Europe

Barry Fox of Great Britain estimates that power consumption from standby will rise dramatically when Great Britain switches to digital TV [4]. Investigations by Hans-Paul Siderius suggest that in the Netherlands, about 10% of household electricity consumption is standby power consumption [5]. Research and investigations in Germany, done by Federal Environmental Agency, show similar results [6].

2.2 Existing Government Programs Designed to Reduce Standby Power

2.2.1 Energy Star

Together with manufacturers, the EPA started to develop guidelines for manufacturing energy efficient home and office products in 1992. In 1997, the EPA introduced the first Energy Star program for home electronics, including TVs, VCRs, and TV/VCR combos. The goal of the program is to reduce standby power. Since then, audio equipment and DVD players have been added to the Energy Star program. Figure 2-1 shows the Energy Star logo that is used on the product to show that it meets the power criteria, i.e. to show that the product is Energy Star compliant. The Energy Star label is on a voluntary basis and the manufacturers perform all the power measurements.

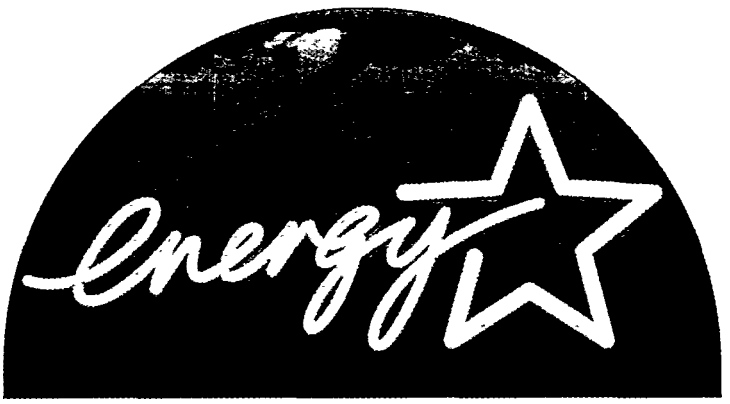

Figure 2-1, Energy Star Label

Currently, the EPA is working together with manufacturers to include set-top boxes. The program is a voluntary partnership between the EPA, the U.S. Department of Energy, and manufacturers. Today there are over 1,200 manufacturer partners that

produce more than 3,400 Energy Star compliant models in 29 product types. The product types include computers, monitors, home heating and cooling equipment, TVs, VCRs, and audio equipment. Table 2-1 shows the criteria for the Energy Star label for some product types [3, 7, 8].

Table 2-1, Criteria for Energy Star label

Product Class	**Standby Power (W)**	**Standby Power 2002 (W)**
TVs	3	-[2]
VCRs	4	-[2]
TV/VCR combos	6	-[2]
DVD players	3	1
Audio Equipment	2	1
Set-top boxes (Analog cable boxes, digital converters, Internet terminals, video game consoles, and videophones)	3[3]	-[2]
Set-top boxes (Digital cable boxes, DBS[4] systems, and boxes with digital video recording capability)	15[3]	-[2]

By promoting energy efficient appliances with equal or better performance, the Energy Star program will lead to reduced air pollution and reduced electricity bills for consumers. If all Americans switched to Energy Star compliant TVs and VCRs, over $500 million would be saved on energy bills each year [9].

2.2.2 GEA Energy Label (Europe)

In March 1996 a workshop was organized, initiated by The Danish Energy Agency (DEA), The Netherlands Agency for Energy and the Environment (NOVEM), Swedish National Board for Industrial and Technical Development (NUTEK), The European Energy Network (EnR), and The Swiss Federal Office of Energy (SFOE), where it was decided to formulate a Memorandum of Understanding as a basis for collaboration [10]. Since then, energy agencies from several other European countries have joined the Group for Efficient Appliances (GEA). The goals of the GEA are to establish a uniform European-wide program for more energy efficient appliances. For that reason, a recognizable energy label was launched, shown in Figure 2-2. This label indicates that the product is more energy efficient than others of its type are.

[2] Not yet announced
[3] The Energy Star program for set-top boxes are still under development, so the levels may change.
[4] Direct Broadcast System

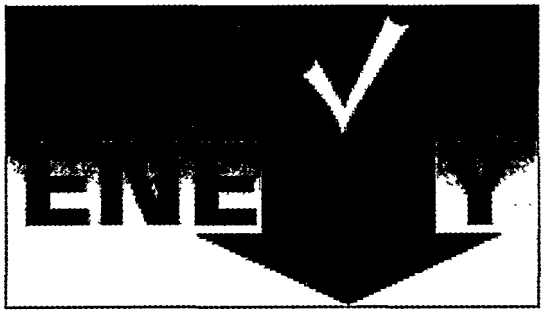

Figure 2-2, GEA's Energy Label

The criteria for receiving the GEA energy label for some products are shown in Table 2-2 [11]. These levels are attained by approximately 25% of the most efficient products on the market. Like Energy Star, the Energy label is on a voluntary basis and the manufacturers perform all power measurements. To motivate manufacturers to participate the registration procedure is kept as simple as possible and free of charge [10].

Table 2-2, Criteria for GEA's Energy Label

Product Class	**Mode**	**Market introduction**	
		Before 01.01.00 (W)	**Between 01.01.00-01.07.00 (W)**
TV with Auto Power off	Standby Passive	7	5
Other TV	Standby Passive	3	1
VCR	Standby Passive	4	3
TV-VCR combos	Standby Passive	4	3
Audio Equipment (including DVD players)	Standby Passive	3	2[5]
Battery Chargers	Standby	1	-[6]
Wall Packs	No-load	0.5	-[6]
Energy Saving Devices	Any operation mode	2	1[5]

2.2.3 Top Runner Program (Japan)

The Ministry of International Trade and Industry (MITI), in Japan, enacted the Law Concerning the Rational Use of Energy in 1979.[7] Paragraph 1 of Article 18 of this law is informally called the "Top Runner" program. This energy efficiency program deals with a variety of products, including air conditioners, fluorescent lamps, TVs, VCRs, computers, copying machines, passenger cars, and trucks.

MITI's method is quite different from the programs of the EPA and GEA. First, Top Runner is not a voluntary labeling program, but a regulation. Manufacturers that do not meet the criteria face fines and public embarrassment. Also, instead of setting a

[5] Market introduction between 01.01.2000 and 01.01.2001
[6] Yet to be announced
[7] Law number 49 of 1979

maximum allowed power level in standby mode, MITI uses a formula to calculate maximum energy consumption per year. For example, Equation 1 shows the formula for high-definition TV sets with double-speed scanning system, where S is diagonal screen size in inches, rounded up to the nearest integer.

Maximum Allowed Energy Consumption per Year = 5.5S+72 kWh/yr (1)

Another formula is then used to calculate the appliance's weighted energy consumption, which is not allowed to exceed the maximum energy consumption calculated in Equation 1. In some appliances, the active mode is included in the formula for weighted energy consumption. Equation 2 shows how to calculate the weighted energy consumption of a TV, where P_O is power during operation in watts, P_S is power during standby in watts, and P_A is reduced power due to power saving functions, in watts.

Appliance Energy = $\{(P_O - P_A / 4) \times 1642.5 + P_S \times 7117.5\} / 1000$ kWh/yr (2)

This is just one example of the many formulas used by MITI in their Top Runner program. Other types of TVs and other appliances use different formulas [12]. So far set-top boxes have not been included in the program.

2.3 Efforts to Reduce Standby Power Internationally

Despite existing government programs to reduce standby power, some organizations are working to implement a plan to transform the electronics market, thereby reducing standby electricity use on a global level. The following sections discuss these efforts.

2.3.1 Lawrence Berkeley National Laboratory (LBNL)

Lawrence Berkeley National Laboratory (LBNL) is operated by the University of California for the U.S. Department of Energy (DOE). Dr. Alan Meier of the Energy Analysis Department at LBNL has proposed a global 1-watt plan for standby power. It calls for a reduction of standby power for all appliances to 1 watt by the year 2010. Based on research done at LBNL and elsewhere, Dr. Meier believes the 1-watt target could be reached with little or no extra cost. With the 1-watt plan, annual U.S. energy costs could be reduced by over $2 billion and carbon dioxide emissions would be reduced significantly. He estimates that about eight nuclear power plants are needed to supply standby power in the U.S. With a 1-watt plan about 70% of this standby power use could be eliminated [13].

2.3.2 International Energy Agency (IEA)

IEA is an energy forum, based in Paris, for 25 member countries. It is an autonomous agency linked with the Organization for Economic Co-operation and Development (OECD). The IEA is currently developing an international strategy to reduce standby power. As a first step the IEA hosted several workshops on standby losses to better understand of the size of the losses and ways of reducing them.

3 Set-top Boxes - Functions and Modes

Set-top boxes are home communications terminals used to process signals for viewing on a television set. Currently, consumers use set-top boxes mainly for TV program reception. In addition to this service, newer set-tops are capable of Internet connections, digital recording, and video games. The set-top of the future is expected to be a complex device that offers a variety of services and functions.

Set-top boxes can be categorized as follows:

- Cable boxes, analog and digital
- Satellite receivers, analog and digital
- Digital decoders, DTV[8] converters, HDTV[9] converters
- Digital Video Recorders
- Internet terminals
- Cable modems

Some of the important functions of existing and future set-top boxes include:

- Converter
- Descrambler
- Pay per view
- Electronic programming guides
- Communication, Internet connectivity
- DVD, Video gaming, Other

Most set-top boxes are capable of performing a number of these functions, while others are designed to perform only one or two. For example, an old analog cable box may function only as a tuner. Many new digital cable boxes have, in addition, descramblers, enhanced communications features and pay per view functionality.

The following sections describe these set-top box types and functions.

3.1 Types of Set-top Boxes

3.1.1 Cable Boxes

Analog cable boxes are needed to descramble scrambled cable channels, or "premium" channels, and also to allow viewing cable channels on old TVs that cannot receive channels outside the UHF and VHF frequencies. Cable customers that do not have such a "cable-ready" television set must use a cable box to receive cable programming. Cable boxes are also required to enable some non-standard cable TV services, such as pay per view or video on demand.

Cable TV signals can be either analog or digital. Since digital signals can be compressed without losing information, more information can be transmitted compared to analog signals at the same bandwidth. This means that digital cable can

[8] Digital TV
[9] High Definition TV

offer more services, and as a result, digital cable boxes tend to have greater functionality and use more power.

Analog Cable Boxes

Some older analog cable boxes are non-addressable, which means that the service provider cannot communicate with the box over the cable. If a customer with a non-addressable box requests a change in service, the descrambling unit or the entire box must be changed. If the customer has an addressable box, the cable company can simply send information over the cable to tell the box what programs to let through.

Digital Cable Boxes

In addition to descrambling premium channels, digital cable boxes are also used to convert digital signals to a standard, for example PAL or NTSC, that can be displayed on an analog TV set. Since these boxes are all addressable, the cable company can program the boxes to descramble the channels and services to which the viewer subscribes via the cable system.

3.1.2 Satellite Receivers

Satellite subscribers require a satellite receiver to use information received by satellite dishes. Satellite transmissions can be either analog or digital. Just like digital cable, digital satellite services typically include more functions than analog services. Newer digital satellite receivers also include functions like pay per view, digital video recording, electronic programming guide, and Internet TV. Digital satellite receivers are integrated receiver decoders (IRD-S[10]) and include decoders to decode the digital signals. Most boxes in the U.S. are digital while they in the EU are analog.

To view channels and use other services, consumers usually have to pay for a subscription to a satellite television service. To commence the subscription, the operator sends out a signal to activate the box.

Information about the subscription can be stored on a programmable smart card or in the box itself. Satellite boxes that do not have smart cards must be addressable. If the receiver does have a smart card, the box itself does not have to be addressable because the address of the box is contained in the smart card. This also means that the services can be used in any satellite receiver that is compatible with the service. If the viewer wants to change the services or add channels the smart card can be reprogrammed from the operators computer.

Many boxes are also equipped with a telephone based modem for two-way communications. With the increasingly popularity of wireless communications, future two-way boxes may use wireless transmission instead.

Satellite receivers all have processors and accompanying software. To prevent them from being obsolete in the near future, they are designed to send information about their software versions to the service provider so that the service provider can upgrade the software over the network.

[10] Integrated Receiver Decoder - appliance for the reception of digital broadcast signals by satellite (IRD-S), cable (IRD-C) or terrestrial (IRD-T).

3.1.3 Digital Decoders

To be able to view digital terrestrial broadcasts, a digital receiver is needed. Consumers that do not want to purchase an expensive DTV or HDTV ready TV set can buy a digital decoder to convert the digital signal to an analog signal for viewing on an analog TV.

Digital decoders can also be used to convert an incoming digital signal to another digital format recognized by the TV set. Because digital TV is still a relatively new phenomenon, functions such as pay per view, personal TV, electronic programming guide, Internet TV are not frequently found in digital decoders; however, integrated devices with enhanced functionality are expected to be popular in the near future.

3.1.4 Digital Video Recorders

Digital video recorders (DVRs) have built-in data storage that can be used to save TV programs in digital format. Some digital recorders record everything the consumer watches, so the, consumer can pause a show, watch a sequence again, or make an instant replay. For example, if the phone rings the show can be paused. Later when there is a break or commercials, the fast forward function can be used to catch up with the live broadcasting. Digital video recorders can also be used to record whole programs or shows for later viewing. Programs may also be transferred to a VCR, to preserve the limited space on the hard drive.

3.1.5 Internet Terminals

Internet terminals allow surfing the Internet and sending e-mail using a TV instead of a computer monitor. To connect to the Internet, a modem or a two-way satellite connection is used. The incoming signals can be received via the telephone lines or the same way that the TV signals are received; i.e. via cable, terrestrial broadcast, or satellite. To send information the box uses a modem or a two-way satellite connection. Most of these boxes also allow keyboard and printer connections.

3.1.6 Cable Modems

The way a cable modem is used is very similar to a telephone line based computer modem, but it is connected to the cable system instead of the telephone line. Cable connections are usually much faster than telephone-line connections, and the telephone line is not blocked while connected to the Internet.

3.2 Set-top Functions

3.2.1 Converter

To receive other signals than the ones the TV is made for, some kind of signal converter is needed. For example, some old TVs cannot receive channels outside the UHF and VHF frequencies, so a converter or modulator that converts the channels to a lower channel is needed. Other examples of converters, are the digital/analog converter and different kinds of digital format converters. Digital/analog converters are found in digital cable boxes, digital terrestrial receivers and digital satellite receivers. These converters convert the digital signals to analog, to allow viewing digital broadcasting on analog TVs. This function is only needed in active mode.

3.2.2 Descrambler

Most movie and premium channels are scrambled, to disallow unauthorized viewing. To be able to view these channels, a descrambler is needed. The descrambling unit in most non-addressable cable boxes is a filter that lets only the channels paid for through, or an inverter that reverts inverted pictures back to their original form. In an addressable cable box, the cable company tells the box what to let through or descramble. There are two kinds of descrambling technologies used in addressable analog cable boxes: RF descrambling and baseband descrambling. RF descrambling uses either gated or pulsed synchronization suppression or sine wave synchronization suppression. Baseband descrambling is considered more secure but is more complex and expensive. For the descrambler to work, the descrambling method must be the same as the scrambling, i.e. the descrambling has to be the inverse of the scrambling. In digital boxes a conditional access system is used to decode or descramble the signal before it is passed to a demultiplexer and MPEG decoder. If the user has authorization to use the service the signal will be descrambled. A smart card is used to store the authorization information. Since descrambling is only used when watching TV or using the services, this function is only used in active mode.

3.2.3 Pay per view

Pay per view is a function, found in most new boxes, used for ordering special shows and events that are not offered in standard service. This means that one pays for only what one watches. When there is a program available for purchasing, the service provider sends out a signal to the box to tell the viewer that ordering is possible. Newer set-top boxes are capable of two-way communication over the main transmission channel, so that the consumer can use the remote control to send the requests to the service provider. Older boxes sometimes use an analog modem to send signals via telephone lines. In some cases, the viewer has to telephone the order to the service provider. When the program is ordered, the service provider sends a signal to the box to descramble or let the signal through. The pay per view function is usually used in active mode, but it could be used in standby mode to receive information about what is available to order later.

3.2.4 Electronic Programming Guide (EPG)

An electronic programming guide is an interactive TV guide. This TV guide is updated regularly by the service provider, so the user can always see what is on TV. It is also possible to create personal TV lists with all the user's favorite channels. If there is a favorite show or program the user do not want to miss, the electronic programming guide can be programmed to automatically switch channels when that show starts. The electronic programming guide can also be used to program VCRs. In the menu of programs, the user can select a show to record. Then the electronic programming guide, with the help of an IR blaster, can transfer the required data to the VCR. The EPG mainly downloads information in standby mode.

3.2.5 Communication/ Internet Connectivity

Most new set-top boxes have to be able to communicate with the service provider to work properly. This communication is commonly used to update software and receive information for electronic programming guides. The update is downloaded the same way as TV signals are transmitted, but to receive the right software version or other information, the box has to tell the service provider who it is and what it needs. This communication is mostly done in standby mode.

Set-tops with Internet connectivity have modems and software that allow access to the Internet using a TV. Information to and from the Internet is accomplished via the same channel as the TV signals, for example via cable, terrestrial broadcast, or satellite, or via the telephone-lines. If a cable modem is used, the signals are both received and sent through the cable system. These boxes typically include ports for connecting peripherals such as keyboards and printers. This function is only used in active mode.

3.2.6 DVD, Video Gaming and other functions

Other functions that can be found in set-top boxes include DVD players, video gaming, and telephony. These are all function used in active mode only. DVD players are usually sold as separate boxes, and some people would not define them as set-top boxes since they do not necessarily receive any external signals. Another function that also usually comes as a separate box is video gaming. Some video game consoles have modems and Internet connectivity. Different kinds of telephony services can also be found in set-top boxes, for example videophones. Set-top boxes with videophone functions can be connected to the telephone line and a digital camera.

4 Energy Consumption of Set-top Boxes in 1999

In this chapter the power consumption and energy use of set-top boxes in the U.S. and the EU are investigated and compared. The only boxes worth considering for 1999 are cable boxes, satellite receivers, and game consoles. Other types of set-top boxes exist in a very small number and do not have a significant influence on set-top power consumption for 1999. The number of other types of set-top boxes is expected to grow considerably in the next couple of years. This will be discussed in chapter 7.

4.1 Power

Table 4-1 shows the different modes that are considered in the power measurements for set-top boxes.

Table 4-1, Description of Modes in Set-top Boxes

	Description
Active	The unit is plugged in and the power switch is in the "on" position
Standby	The unit is plugged in and the power switch is in the "off" position.

LBNL measured power levels of a sample of satellite receivers, cable boxes, and game consoles to use in the estimations of set-top energy consumption in the U.S. The data collected showed that older and newer cable boxes did not vary much in power requirements. Figure 4-1 and Table 4-2 show the results of the measurements .

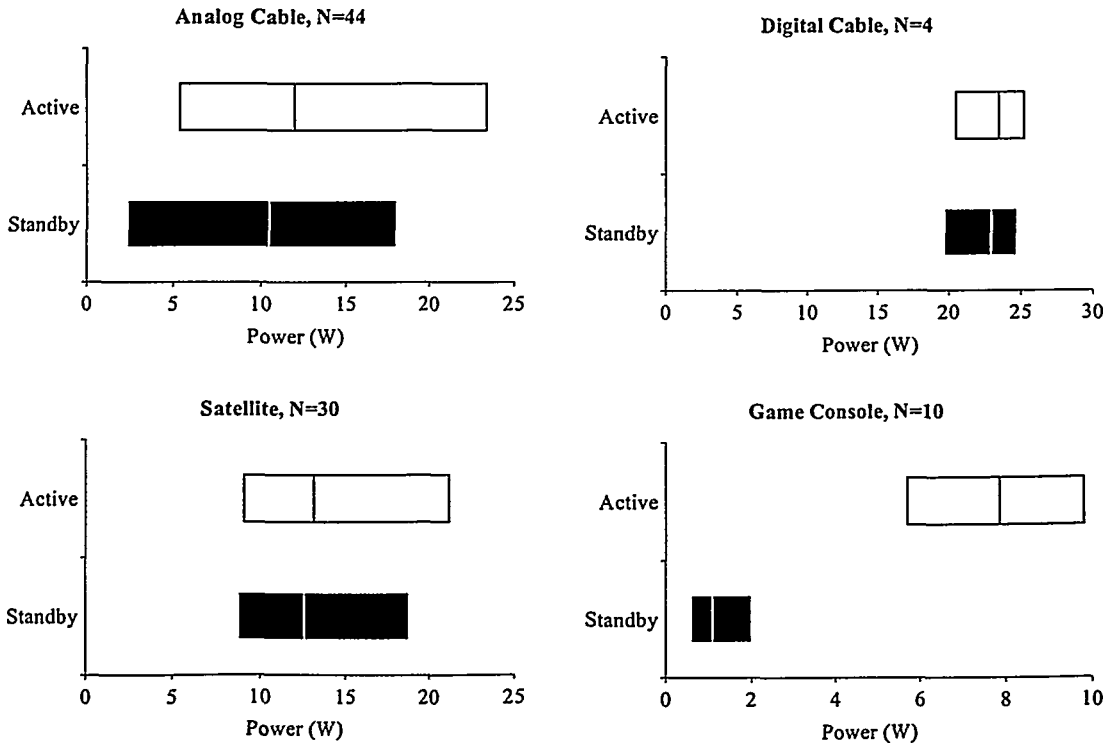

Figure 4-1, Minimum, Mean, and Maximum Power Draw Values of Set-top Boxes in the U.S. [14]

The power levels for set-top boxes in the EU, have been collected from data sheets and manuals from different manufacturers represented in the EU. Data from measurements have also been collected from other reports on set-top boxes in the EU [15]. Data have been collected from boxes in all the EU countries. It is assumed that the game consoles in the EU are the same as in the U.S. Table 4-2 shows average power requirement for different set-top boxes.

The measurements show that digital set-top boxes require much more power than analog set-top boxes. The digital cable boxes are new products and are likely to be more power efficient as the market matures. The measurements also show that standby power in game consoles is low, and the difference between analog and digital satellite receivers in the EU is small. There are almost no analog satellite receivers in the U.S. so no measurements have been done.

Table 4-2, Average Power Requirements of Set-top Boxes in Watts.

	Standby		Active	
	U.S.	EU	U.S.	EU
Cable, Analog	10.5	11.0	11.9	12.4
Cable, Digital	22.9	5.0	23.5	25.0
Satellite, Analog	-	7.9	-	20.5
Satellite, Digital	16.5	7.6	17.0	23.4
Game Console	1.1	1.1	7.9	7.9

4.2 Usage

Most set-top boxes are on when the TV they are connected to is on. The usage pattern for set-top boxes can therefore be derived from TV usage patterns. In the U.S., LBNL estimated that TVs in homes are active 22% of the time (5.5 hours/day) and that set-top boxes are on at the same time. Video game consoles are estimated to be on about 20% of the time even though they are used only about 1% of the time. Table 4-3 shows the usage patterns for set-top boxes [14]. The usage patterns are assumed to be the same in the U.S. and the EU.

Table 4-3, Set-top Usage Patterns

	Standby	On
Cable, Analog	78%	22%
Cable, Digital	78%	22%
Satellite, Analog	78%	22%
Satellite, Digital	78%	22%
Game Console	80%	20%

4.3 Stock

The estimates of U.S. set-top stock have also been done by LBNL. They estimated the number of cable boxes and satellite receivers based on the number of cable and

satellite subscribers. The number of video game consoles was taken from TV Dimensions 1998. The stock estimates of cable boxes, satellite receivers, and game consoles in the EU are from a survey done by Inestene, France [16]. The fraction of cable boxes and satellite receivers that are digital in the EU are estimated to be 5%. Table 4-4 shows the number of set-top boxes in the U.S., the EU, and Sweden.

Table 4-4, Number of Set-top Boxes in 1999

Product	U.S.	EU	Sweden
	(millions)	(millions)	(millions)
Cable Box, Analog	38	13.7	0.2
Cable Box, Digital	3.6	0.7	0.01
Satellite, Analog	-	32.2	1.2
Satellite, Digital	16	1.7	0.06
Game Console	54	22.7	0.6

In the U.S. the most common set-top boxes are game consoles while in the EU the most common boxes are analog satellite receivers. In the U.S. almost no analog satellite receivers exist.

4.4 Energy

When power, usage patterns, and stock data are known, Equation 3 can be used to calculate average energy consumption per unit (UEC[11]). P_S and P_A are the average power consumption (kW) in standby and active mode respectively, and T_S and T_A are the percentage of time the set-top box is in standby and active mode respectively. To get the result in kWh/yr the power consumption is multiplied by 8760, which is the number of hours per year. Table 4-5 shows the average energy consumption of set-top boxes in the U.S. and the EU. Table 4-6 shows the average energy consumption of set-top boxes by mode.

$$UEC=(P_S \times T_S + P_A \times T_A) \times 8760 \quad \text{kWh/yr} \qquad (3)$$

Table 4-5, Average Energy Consumption Per Unit.

Product	U.S.	EU
	(kWh/yr)	(kWh/yr)
Cable Box, Analog	95	99
Cable Box, Digital	202	82
Satellite, Analog	-	93
Satellite, Digital	143	97
Game Console	21	21

[11] Unit Energy Consumption

Table 4-6, Average Energy Consumption Per Unit by Mode

Product	Standby		Active	
	U.S.	EU	U.S.	EU
	(kWh/yr)	(kWh/yr)	(kWh/yr)	(kWh/yr)
Cable Box, Analog	72	75	23	24
Cable Box, Digital	157	34	45	48
Satellite, Analog	-	54	-	39
Satellite, Digital	86	52	33	45
Game Console	8	8	14	14
	(%of UEC)	(%of UEC)	(%of UEC)	(%of UEC)
Cable Box, Analog	76%	76%	24%	24%
Cable Box, Digital	78%	41%	22%	59%
Satellite, Analog	-	58%	-	42%
Satellite, Digital	77%	53%	23%	47%
Game Console	36%	36%	64%	64%

Table 4-5 and Table 4-6 show that, except for the analog cable boxes, the boxes in the EU are more energy efficient than the boxes in the U.S. in standby mode. In active mode most boxes use almost the same amount of power in the U.S. and the EU, except for the digital satellite receivers, which are more efficient in the U.S.

By multiplying average energy consumption by the number of units, the energy consumption of set-top boxes can be calculated for each mode. The results of this calculation are shown in Table 4-7, Table 4-8, and Table 4-9. Table 4-10, Table 4-11, and Table 4-12 show the share of residential electricity use, consumed by set-top boxes.

Table 4-7, Energy Use of Set-top Boxes in the U.S. in 1999, by Mode

Product	Standby	Active	TPE[12]
	(TWh/yr.)	(TWh/yr.)	(TWh/yr.)
Cable Box, Analog	2.7	0.9	3.6
Cable Box, Digital	0.6	0.2	0.7
Satellite, Analog	-	-	-
Satellite, Digital	1.8	0.5	2.4
Game Console	0.4	0.7	1.2
Mode Energy Use	5.5	2.3	7.9
	(% of TPE)	(% of TPE)	(% of TPE)
Cable Box, Analog	76%	24%	100%
Cable Box, Digital	78%	22%	100%
Satellite, Analog	-	-	-
Satellite, Digital	77%	23%	100%
Game Console	36%	64%	100%
Mode Energy Share	70%	30%	100%

NOTE: Figures may not add due to rounding.

[12] Total Product Energy Use

The total amount of energy consumed by set-top boxes in the U.S. is 7.9 TWh every year. Of this energy 70% or 5.5 TWh is energy used in standby mode. All the boxes, except for game consoles, use over 76% of the energy in standby mode. Because of the low standby power in game consoles they use only 36% of the energy in standby mode.

Table 4-8, Energy Use of Set-top Boxes in the EU. in 1999, by Mode

Product	Standby	Active	TPE
	(TWh/yr.)	(TWh/yr.)	(TWh/yr.)
Cable Box, Analog	1.0	0.4	1.4
Cable Box, Digital	0.0	0.0	0.1
Satellite, Analog	1.7	1.3	3.0
Satellite, Digital	0.1	0.1	0.2
Game Console	0.2	0.3	0.5
Mode Energy Use	3.1	2.0	5.1
	(% of TPE)	(% of TPE)	(% of TPE)
Cable Box, Analog	76%	24%	100%
Cable Box, Digital	41%	59%	100%
Satellite, Analog	58%	42%	100%
Satellite, Digital	53%	47%	100%
Game Console	36%	64%	100%
Mode Energy Share	60%	40%	100%

NOTE: Figures may not add due to rounding.

In the EU the total amount of energy used by set-top boxes is 5.1 TWh every year. The energy used in standby mode is about 3.1 TWh, which corresponds to about 60% of the total energy. The Active energy consumption in EU is almost the same as in the U.S., 2.0 TWh, while in standby mode there is a big difference. Most of the boxes are close to have half of the energy use from active mode. The exceptions are analog cable boxes and game consoles. Analog cable boxes have only 24% of the energy from active mode and game consoles have 64% of the energy from active mode.

Table 4-9, Energy Use of Set-top Boxes in Sweden in 1999, by Mode

Product	Standby	Active	TPE
	(GWh/yr.)	(GWh/yr.)	(GWh/yr.)
Cable Box, Analog	16.5	5.2	21.7
Cable Box, Digital	0.4	0.6	1.0
Satellite, Analog	66.3	48.3	114.7
Satellite, Digital	3.3	2.9	6.2
Game Console	4.6	8.3	12.9
Mode Energy Use	91.2	65.3	156.5
	(% of TPE)	(% of TPE)	(% of TPE)
Cable Box, Analog	76%	24%	100%
Cable Box, Digital	41%	59%	100%
Satellite, Analog	58%	42%	100%
Satellite, Digital	53%	47%	100%
Game Console	36%	64%	100%
Mode Energy Share	58%	42%	100%

NOTE: Figures may note add due to rounding.

Since the same boxes exist in Sweden and the EU the fraction of energy used in standby is the same. The difference is the total amount of energy used by set-top boxes. In Sweden the energy use by set-top boxes is about 0.16 TWh every year. That is about 3% of the energy used by set-top boxes in the EU.

Table 4-10, National Energy Consumption Estimates for Set-top Boxes in the U.S. in 1999

Product	Energy Use in the U.S. (TWh/yr.)	Share of Set-top Energy Use	Share of Residential Electricity Use in the U.S.
Cable Box, Analog	3.6	46%	0.32%
Cable Box, Digital	0.7	9%	0.06%
Satellite, Analog	-	-	-
Satellite, Digital	2.4	30%	0.21%
Game Console	1.2	15%	0.10%
Total U.S.	7.9	100%	0.70%

The product that uses most energy in the U.S. is analog cable boxes with 3.6 TWh every year or 46% of the set-top energy use. Game consoles use only 1.2 TWh every year or 15% of the total set-top energy use, even though it is the most common box in the U.S. The total amount of electricity used by set-top boxes in the U.S. corresponds to 0.70% of the total residential electricity use.

Table 4-11, National Energy Consumption Estimates for Set-top Boxes in the EU in 1999

Product	Energy Use in the EU (TWh/yr.)	Share of Set-top Energy Use	Share of Residential Electricity Use in the EU
Cable Box, Analog	1.4	27%	0.23%
Cable Box, Digital	0.1	1%	0.01%
Satellite, Analog	3.0	59%	0.50%
Satellite, Digital	0.2	3%	0.03%
Game Console	0.5	10%	0.08%
Total EU.	5.1	100%	0.85%

With 3.0 TWh every year, analog satellite receivers is the product that uses most of the set-top energy in the EU. That is about 59% of the total set-top energy use. It is also the most common set-top box in the EU. Like in the U.S. game consoles use a relatively small fraction of the total set-top energy. While analog cable boxes uses almost half of the set-top energy in the U.S. they only use about 27% of the set-top energy in the EU. In the EU, the total amount of electricity used by set-top boxes corresponds to 0.85% of the total residential electricity use.

Table 4-12, National Energy Consumption Estimates for Set-top Boxes in Sweden in 1999

Product	Energy Use in Sweden (GWh/yr.)	Share of Set-top Energy Use	Share of Residential Electricity Use in Sweden
Cable Box, Analog	21.7	14%	0.05%
Cable Box, Digital	1.0	1%	0.002%
Satellite, Analog	114.7	73%	0.28%
Satellite, Digital	6.2	4%	0.02%
Game Console	12.9	8%	0.03%
Total Sweden	156.5	100%	0.38%

In Sweden analog satellite receivers have an even bigger share of the total set-top energy use than the EU with 73% or 114.7 GWh every year. That is a bigger share than both the U.S. and the EU. Analog cable boxes use only about 21.7 GWh/yr or 14% of set-top energy use. The total electricity used by set-top boxes in Sweden is about 0.38% of the total residential electricity use. That is lower than both in the U.S. and in the EU.

5 Standby Power in Set-top Boxes

Most set-top boxes consume a large amount of electricity, even when they are not in use. There are three major reasons for this energy use; inefficient power supplies, inefficient circuitry, and components that are active when not needed and time when boxes are waiting for downloads.

5.1 Jerrold CFT2024

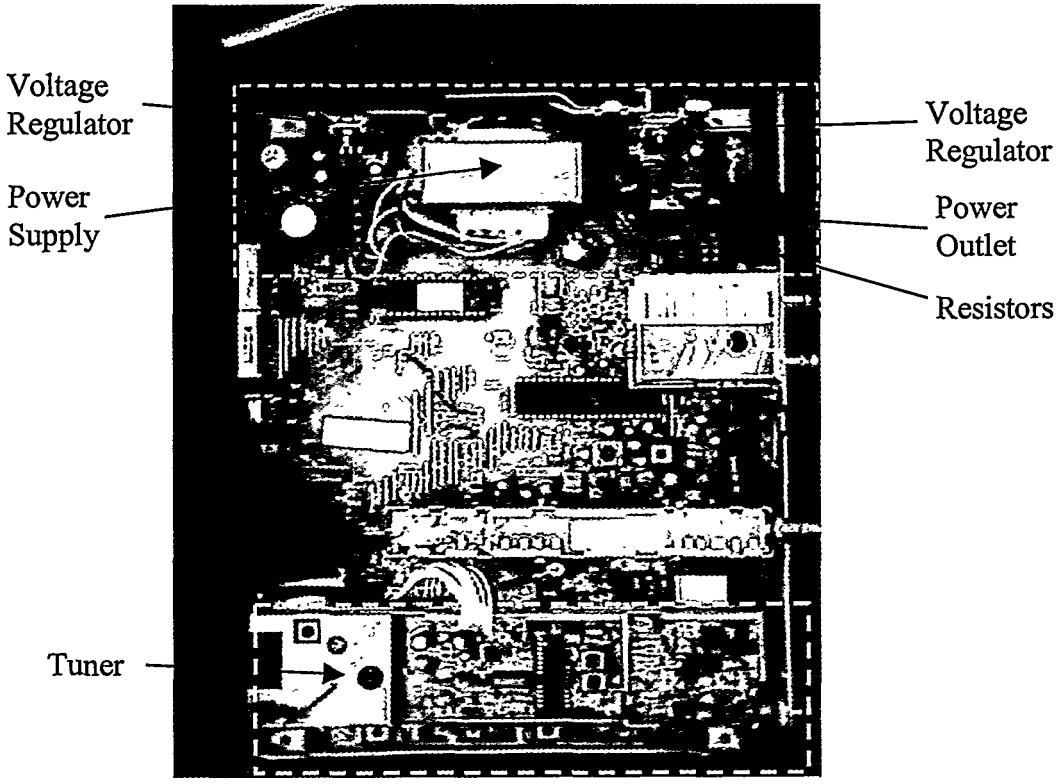

Figure 5-1, Photo of the Jerrold CFT2024

An example of a box with high standby power consumption is the analog cable box, Jerrold CFT2024, shown in Figure 5-1. When active it uses 13.1 watts and in standby mode it uses 12.0 watts. This high standby energy use is because most circuitry is still powered and the efficiency of the power supply is poor. Figure 5-2 and Figure 5-3 show IR-photos of the Jerrold CFT2024 in active mode and standby mode, respectively.

Figure 5-2, IR-Photo of the Jerrold CFT2024 in standby mode

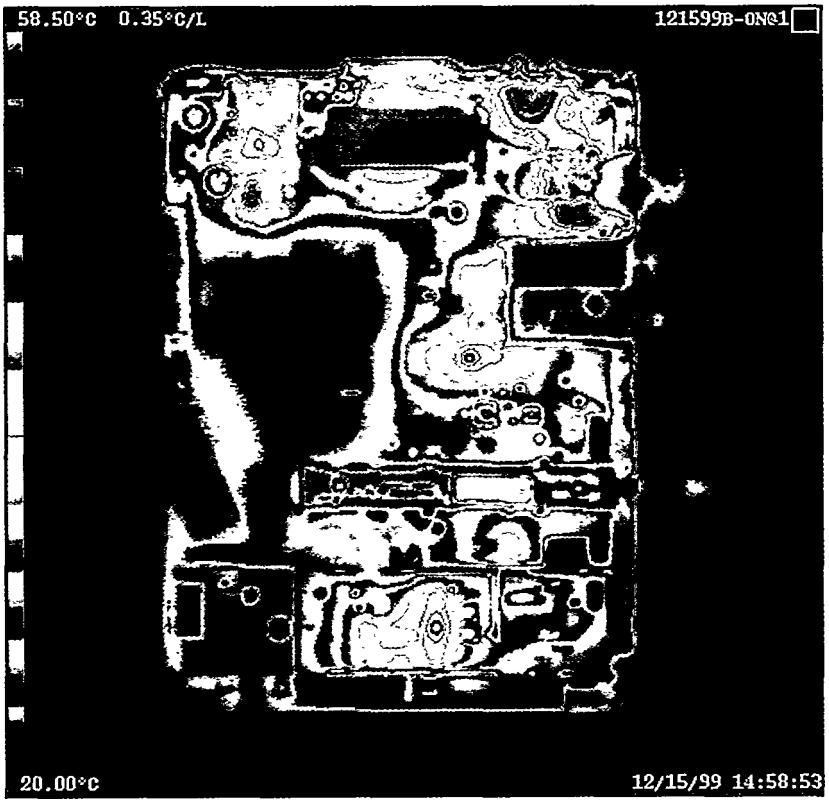

Figure 5-3, IR-Photo of the Jerrold CFT2024 in active mode

The red areas in Figure 5-2 and Figure 5-3 are warm components, indicating energy losses. It clearly shows that the difference in energy use between standby mode and active mode is very small.

Many of the components could be shut off when the box is not in use. As the pictures show, the tuner for example is powered even when the box is in standby mode, which is not necessary. The only components that seem to be shut off in standby mode are the display and the power outlet for the TV. The only components that need to be powered in this box are the IR-sensor and some control circuit for the sensor. On the bright side, if the outlet power is cut, and the TV is connected to this outlet, the standby losses in the TV will be eliminated.

5.2 Echostar Dishplayer

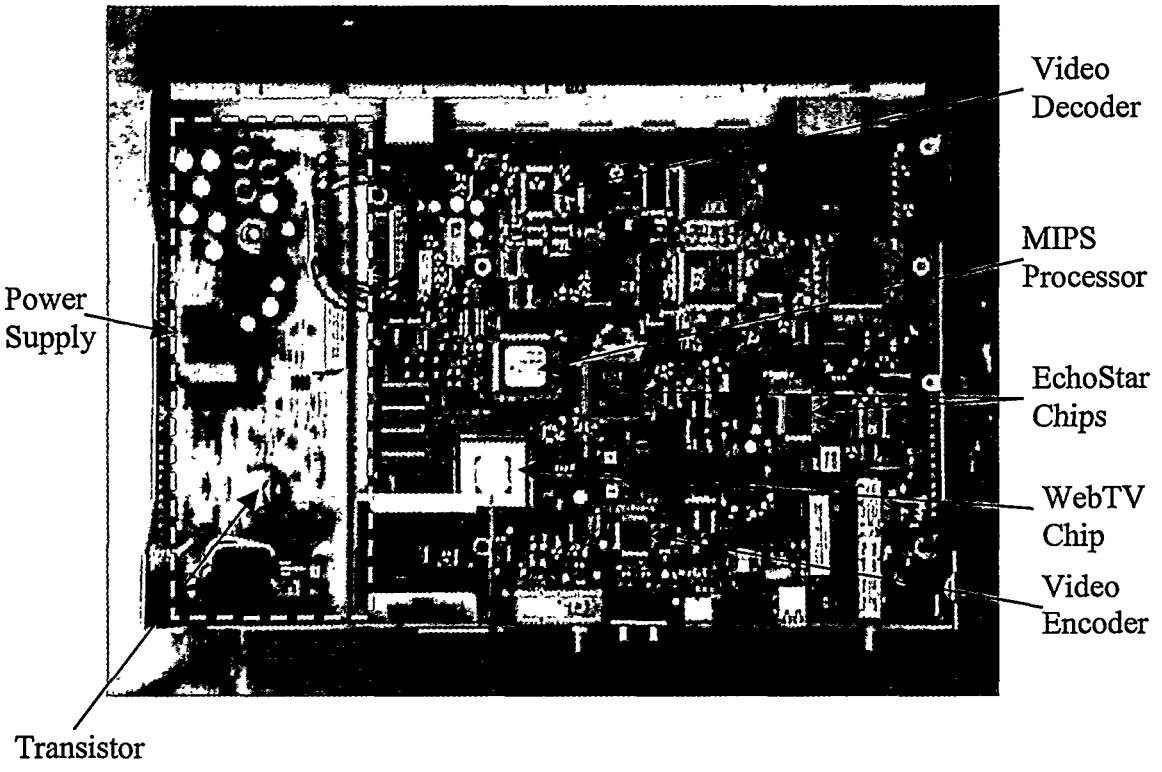

Figure 5-1, Echostar Dishplayer

The Echostar Dishplayer, a digital satellite receiver, provides another example of high standby energy use. The Echostar Dishplayer is shown in Figure 5-1. When in standby mode, it uses 21 watts, and in active mode, it uses 30 or 26 watts, depending on whether the built in hard drive is spinning or not. In this box, the high energy use is because most circuitry is powered even when it is in standby mode. The power supply in this set-top box is a switch mode power supply (SMPS), which has a much better efficiency than the linear power supply in the Jerrold CFT2024. One reason for the circuitry to be powered in standby mode is so that the box is always ready to download TV listings and software updates. Figure 5-2 and Figure 5-3 show IR-photos of the Echostar Dishplayer in standby mode and active mode, respectively.

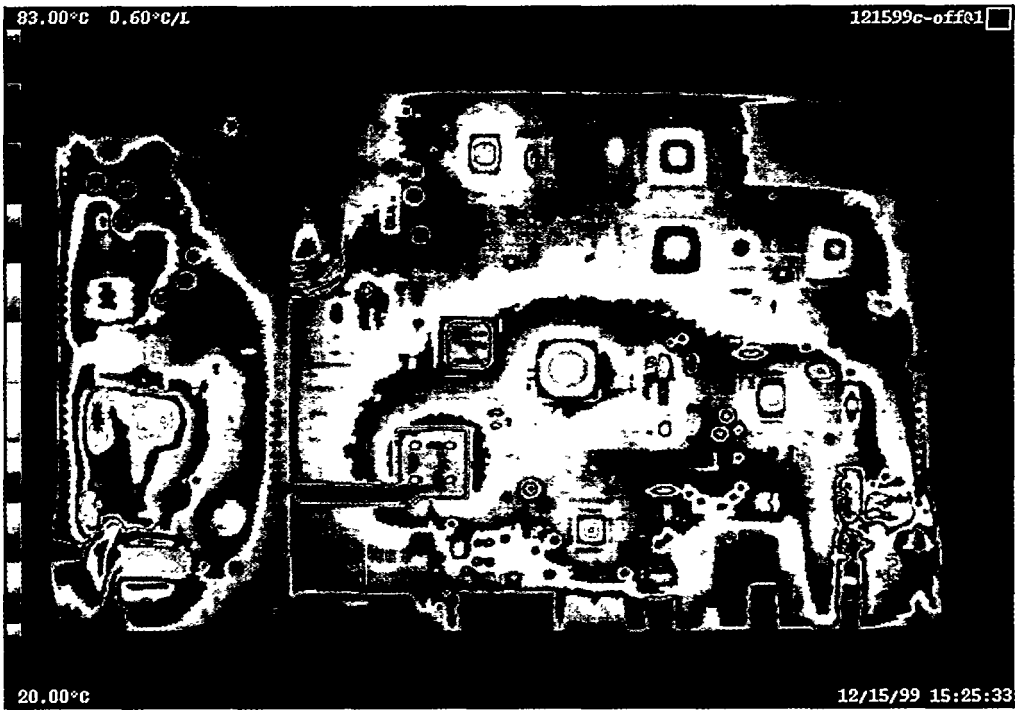

Figure 5-2, IR-Photo of the EchoStar DISHPlayer in standby mode

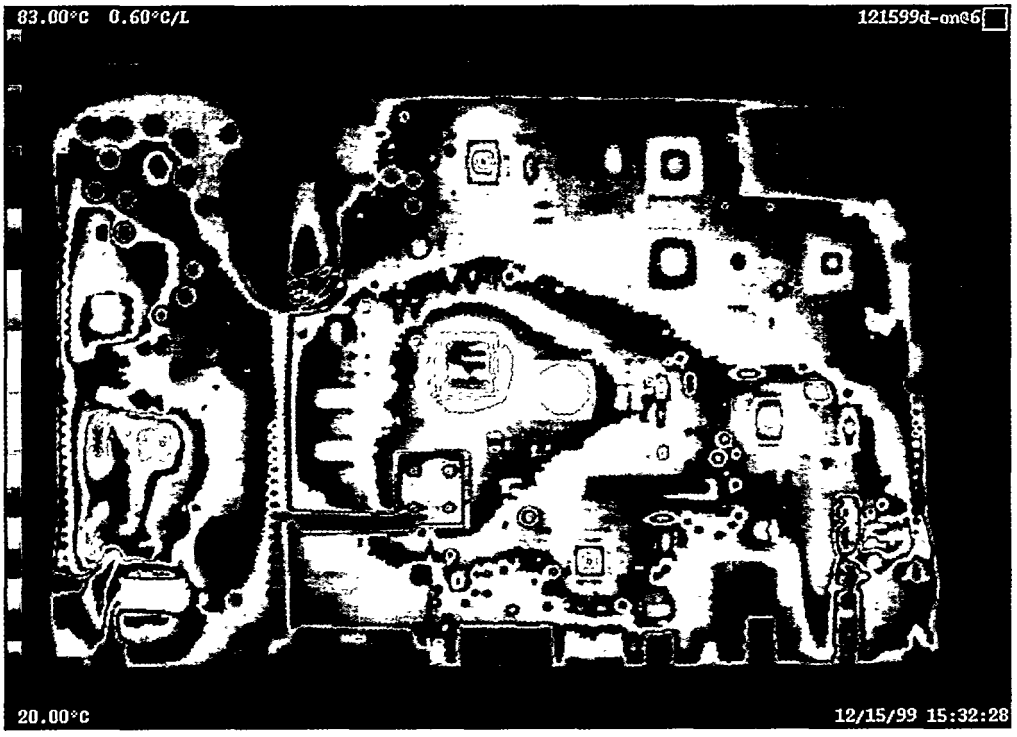

Figure 5-3, IR-Photo of the EchoStar DISHPlayer in active mode

The IR-photos of the Echostar Dishplayer show that the video encoder and decoder are on even when the box is in standby mode. When the box is not in use, there are no video signals to encode or decode, so it seems unnecessary to have these components powered in this mode. Also, the WebTV chip is powered when it is not used to browse the Internet. Some power to the processor is needed in standby mode to be able to process signals from the remote and to be able to download information.

Even though it is used in standby mode, the processor seems to using less power in standby mode than in active mode. If it is possible to have a lower power mode for the processor in standby mode and still be able to recognize signals from the service provider, the processor should also be able to control the power supply to the rest of the circuits.

In the following chapter, suggestions on how modest redesigns could increase the efficiency of set-top boxes will be discussed. There are two major ways of improving these boxes: improved hardware, including improved power supply and improved circuitry, and/or improved software including improved communication with service provider.

6 Potential Energy Efficiency Improvements

In most set-top boxes it is possible to reduce the power consumption with relatively modest changes. Examples of boxes that exist today and are relatively energy efficient are the Nokia Mediamaster series with a standby power about five watts. There are two ways of reducing power consumption in set-top boxes. The first one is to reduce power consumption by changing the hardware. This is discussed in section 6.1. The other way is to change the software to reduce the time of activity. This is discussed in section 6.2.

6.1 Hardware: Reduce Power

6.1.1 Power Supply

Since most electronic devices use low-voltage direct current (DC), a power supply is needed. There are two kinds of power supplies used in set-top boxes; linear and switch mode power supplies (SMPS). The SMPS is more efficient than the linear power supply but also more complex and expensive.

Linear Power Supply

A linear power supply consists of a transformer to lower the voltage, a rectifier to change the alternate current to direct current, and some regulators to keep the voltage within a specific range.

Transformers are most efficient at only one load and voltage, so if the transformer is used with other voltages than designed for, the efficiency is poor.

The efficiency of the transformer can be improved by using a lower gauge of wire to reduce the resistance, and by using more and thinner laminations in the core to reduce the leakage inductance.

The simplest rectifier is a diode that cuts the negative current. Usually four diodes are used in combination with a capacitor to make an even better rectifier. There is a voltage loss of about 0.7 volts in a diode corresponding to some loss of power in the rectifier. Diodes that are more efficient could be used, but this is not likely to be cost effective.

Regulators are used to keep the voltage steady. For typical regulators to work properly, the input voltage must be several volts higher than the output voltage. For example between eight and twelve volts are needed for an output of five volts. This results in a lot of power being emitted as waste heat. In a linear voltage regulator, it is difficult to accomplish efficiency above 50%, which means that as much as 50% of the power may be dissipated from regulators [17]. If low dropout regulators are used, the input voltage can be reduced to around 0.1 volts over the output voltage, and losses would be reduced.

SMPS

A switch mode power supply (SMPS) consists of a rectifier to convert the alternating current to direct current, and a transistor to cut the current into short pulses. The output voltage is the mean value of this cut current, and depends on how short or long the pulses are. If the input voltage is 110 volts, and the transistor is letting the current

through 1/10 of the time, the output voltage becomes 11 volts. A converter with this topology is called a buck-converter. There is a variety of different converters, for example flyback-converters, forward-converters, boost-converters, etc. Figure 6-1 shows the principles of cutting the current in an SMPS [17].

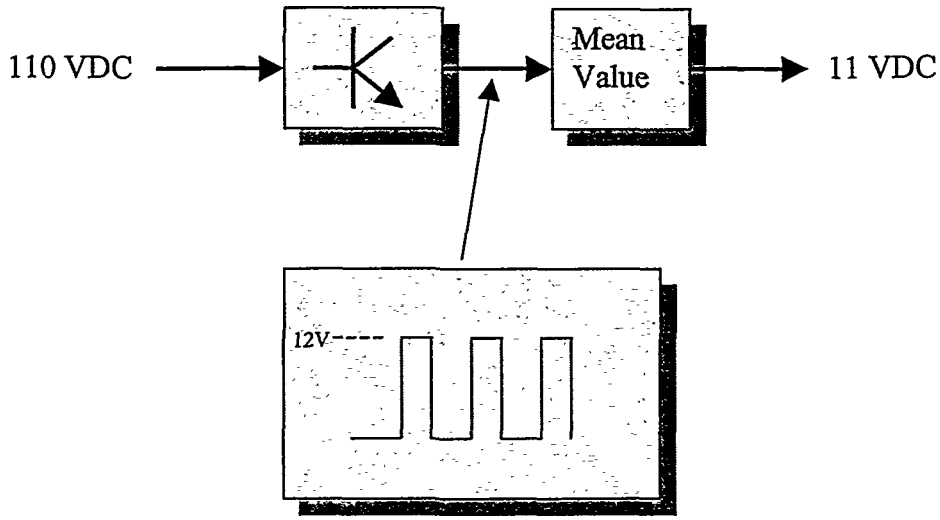

Figure 6-1, Principles of SMPS

The advantage of an SMPS over the linear power supply is that the losses in a transistor are very small, and voltage regulators with poor efficiency are not needed. The disadvantages include a more complex power supply and the risk of radio frequency disturbance.[13] With the use of a filter, this problem can be avoided. Most newer set-top boxes are equipped with an SMPS. With an SMPS, the power used by the power supply in standby can be lower than 0.1 watts. This is discussed in greater detail in section 6.1.2.

6.1.2 Circuitry

By incorporating relatively modest changes in the circuitry, the standby power demand can be lowered. This can be done by using more efficient components, or by cutting the power to parts and components that are not required in standby mode.

Oscillators are used to vibrate at a specific frequency, providing a tempo for operations in a logical device. The higher the oscillator frequency, the more power it, and components following that frequency, consume. In standby mode, an oscillator is still needed for standby functions, but by switching to a lower frequency oscillator, a higher efficiency can be obtained [13].

Power consumption can be reduced significantly by cutting the power to components and parts that are not in use in standby mode. The simplest and most energy efficient way of doing this is to implement a physical switch on the primary side of the power supply. This switch would cut the power to all components. Consumers may not

[13] EMF is generated when the transistor is switching.

approve of this solution because it would eliminate the option of turning on the set-top box with the remote.

An alternative method is to provide power to only the circuitry needed to turn the box on. For example, an infrared remote control needs an IR-receiver and some control circuit to decode the remote signal. These components could remain active using only a few milliwatts.

The same method could be used to turn the box on from the service provider's computer via the antenna input, but since these signals are more complex, more complex decoders and control circuitry would be needed, which means increased power consumption. A better way would be to change the communications protocols, and let the boxes decide when to update software and information. This is discussed in section 6.2.2.

To avoid losses from the main power supply and still get power to the standby functions, a secondary power supply can be added. Since very little power is needed for these functions a small, inexpensive power supply can be used. As a secondary power supply, a small linear or switch mode power supply could be used to provide electricity to the circuitry needed in standby mode. Since the power consumption in standby is low, the energy losses would be small even with a relatively poor power supply.

If the main power supply is an SMPS, it can be connected to act as a secondary power supply in standby mode as showed in Figure 6-2.

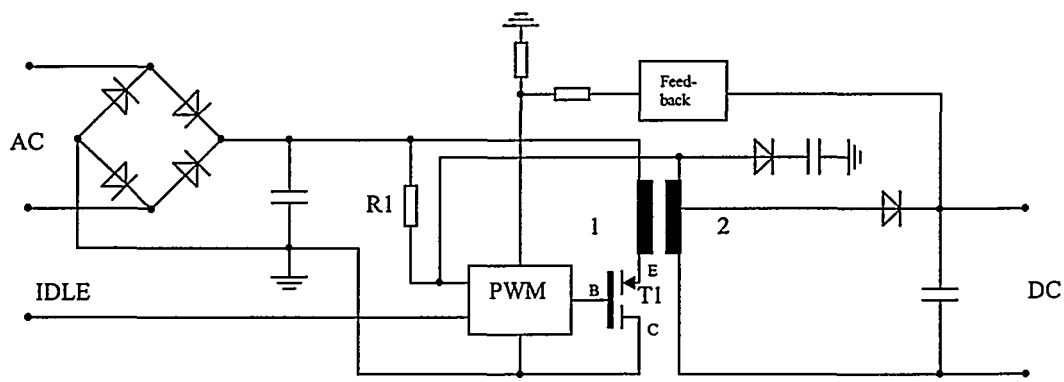

Figure 6-2, SMPS as secondary power supply

The circuit in Figure 6-2 works in the following manner. When the pulse width modulator (PWM) is in idle mode, there will be no current to the base (B), and the transistor (T1) will not let any current from the emitter (E) to the collector (C). If there is no closed circuit on the primary side (1), there will be no power out on the secondary side (2). If the resistance in R1 is very high, the current to the PWM becomes small. This means that the power consumption in the power supply is very small in standby mode. When the user uses the remote (or the on/off button) to turn the device on, an on/off decoder gives the idle pin on the PWM a signal to deliver current to the base (B). When there is a current to the base, the transistor will let

current through from the emitter (E) to the collector (C), and there will be power on the secondary side (2). Since the current to the PWM is not enough from the primary side (1) in on mode, the PWM will be fed from the secondary side (2) in on mode. The standby power in a set-top box with a power supply like this could be as low as a couple of milliwatts [17].

A transformerless power supply could also be used to provide power for the standby functions. The capacitive auxiliary power supply replaces expensive transformers with capacitors. Disadvantages with this power supply, are that it supplies limited current and the power factor is very low, about 0.2. While it is not an alternative for the primary power supply in active mode, in some cases the capacitors may deliver enough current for standby functions.

When a capacitor and a resistor or load are connected in series to an alternate current source and the reactance is much greater than the resistance, a constant current can be maintained through the load. To get DC voltage, a pair of rectifiers and capacitors can be added. A pair of zener diodes can be added to regulate the voltage. Figure 6-3 shows a capacitive auxiliary power supply [18].

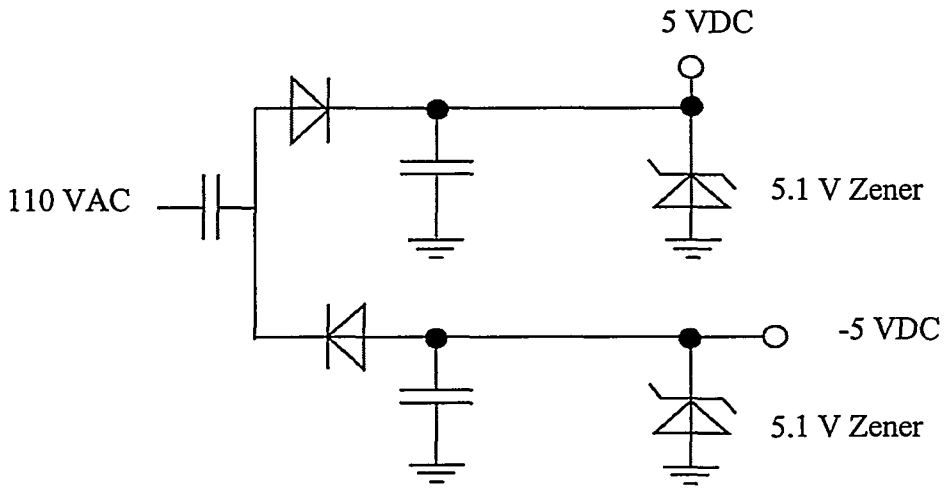

Figure 6-3, Capacitive Auxiliary Power Supply

A small rechargeable battery can also be added to provide power for the standby functions. In standby mode the battery provides the power until it has discharged to a low power level, at which point the main power supply switches on to recharge the battery. When the battery is recharged, the main power supply switches off again, and the battery provides the power.

6.2 Software: Reduce Periods of Activity

6.2.1 Power Management

There is no reason for set-top boxes to be on when the TV is off, except when information is downloaded. When the TV has been off for a predetermined period of time, the set-top box could shut itself off. This requires communication between the set-top box and the TV. Such protocols do not exist.

6.2.2 Data upload/download

Many of the software updates and data downloads to the set-top boxes are done whenever the service provider decides to download or update. This requires that the boxes have many otherwise unnecessary components powered in standby mode. For example components that are only used for the download process are powered all the time. To avoid this, the communications protocols between the boxes and the service providers could be changed to let the user or the box decide when to download new information or data. This is done, for example, in the Nokia Mediamaster series, where the standby power is as low as 3.0 watts for the digital cable box (Mediamaster 9730C), 5.5 watts for the digital satellite receiver (Mediamaster 9800S), and 5.5 watts for the digital terrestrial TV receiver (Mediamaster 9820T). This would probably not be possible in a set-top box that was ready to download all the time.

Updates could also be made on a recurring basis. For example, every night, at a predetermined time, the box could connect to the service provider and check if there is any new software or information to download. This could be done with a timer, which turns the box on at the same time every night or week. Another solution would be to let the box check for updates every time it is shut off. Before it goes into standby mode, it connects to the service provider to download new information.

7 Discussion

7.1 Differences in Set-top Energy Use between the U.S. and the EU

There are several differences between set-top boxes in Europe and the U.S. In Europe many appliances and electrical devices have an off switch that lets the user turn the devices off. In this off mode, set-top boxes are no longer able to respond to the remote or external signals. This off mode does not exist in most set-top boxes in the U.S.

The way the boxes update information also differs between Europe and the U.S. The service providers in the U.S. like to decide when to update information, while in Europe it is the user, in most cases, that decides when to look for an update of information. This means that the U.S. boxes that have this update feature, always have to be ready to receive information. In boxes where it is the user that decides when to update, they only have to be ready to receive information from the remote.

Another difference is the input voltage. In Europe 230 volts and 50 hertz are used while in the U.S. 110 volts and 60 hertz are used, so the power supplies have to be different. This does not have any major influence on the efficiency of the power supply since the efficiency of a power supply is proportional to the power use on the secondary side, and not the input voltage [17].

7.2 Programs Aimed at Reducing Set-top Standby Energy

Different organizations, as EPA and GEA, are working on reducing the amount of energy used by set-top boxes in standby mode. Currently the EPA, together with manufacturers, is working on expanding their Energy Star program to include set-top boxes. They recently announced a draft on standby power limits for set-top boxes. In this draft they divided set-top boxes into two categories with different power levels. The category with the higher 15 watts power level includes digital cable boxes, DBS systems, and digital video recorders. The remaining devices, including analog cable boxes, digital converters, fall into a low-power category at 3 watts. Compared to existing standby power levels, this is a large reduction.

The original specification asked for an 8 watts limit but some manufacturers said that it is not possible to achieve the 8 watts power level goal for satellite receivers, since they have to be able to receive signals from the satellite at almost any time. This means that they have to have power to the antenna, signal processor, and tuner all the time. Measurements at LBNL indicate that about 3.6 watts are needed for the LNB in the antenna to work. As discussed in section 6.2.2, the solution to this could be to change the communications protocols, and let the user decide when to download information. It is technically achievable with modest redesign to achieve these power level goals. The largest obstacle will probably be to convince the manufacturers to change the way they do things and to convince consumers to choose the low energy products. The EPA has also issued lower "Tier 2" levels, which will go into effect at a later date. The "Tier 2" levels are 7 watts for all set-top boxes.

GEA already includes some set-top boxes in their energy label program. Set-top boxes included are digital cable boxes (IRD-C), digital satellite receivers (IRD-S), digital terrestrial receivers (IRD-T), and analog satellite receivers. They also consider

three different modes in the program: off, standby passive, and standby active. The off mode and the standby passive mode are optional. Table 7-1 shows the criteria for the GEA Label [11].

Table 7-1, Criteria for the GEA Label for Set-top Boxes Introduced to the Market Before 01.01.2001

Type	Off (W)	Standby Passive (W)	Standby Active \ Low (W)
IRD-C	0.5	1	7.5
IRD-S	0.5	1	7.5
IRD-T	0.5	1	5
Satellite, Analog	0.5	1	-

Unlike in the U.S., the European boxes seem to have no problems achieving power levels lower than 8 watts for satellite receivers. Standby power requirements in set-top boxes in the EU are in general much lower than in the U.S. One reason is because the communications protocols are different. In most European boxes the user decides when to download information or the information is downloaded when the box is in active mode. Maybe it is about time that manufacturers in the U.S. take a look outside their country to see how things are done in other parts of the world.

7.3 Future

Some of the newer set-top boxes are remarkably power hungry. For example, one of the newer personal video recorders in the U.S. uses 60 watts when it is on and it has no off button. A device like this would cost the user about $50 every year in electrical bills. Another example is a combination of an HDTV decoder and satellite receiver that uses over 30 watts in both on and off modes.

Terrestrial Broadcasting

The Federal Communications Commission in the U.S. plans that every TV in the U.S. will be replaced by a digital TV or equipped with a digital converter set-top box by 2006. The digital TV sets will not use considerably more energy than the analog TV sets, but market research surveys show that most people are not going to replace their analog TV sets with expensive digital sets. Most people plan to purchase or rent a digital converter set-top box, to use with their old analog TV sets. LBNL estimates that the addition of digital broadcast converters to U.S. TV sets will increase household energy consumption by 300-400 kWh annually [19]. The same thing is expected to happen in the EU, where most countries are planning, or have already started, to broadcast digital terrestrial. Most of the early DTV decoders were standalone units; however, efforts to create a universal set-top box specification for DTV decoders ensure that DTV decoding functionality will be integrated into multifunction set-tops [20]. Integrated DTV/satellite decoder boxes were available as early as in January 2000.[14]

[14] The RCA xxx100

Cable Service

Most cable companies are currently introducing or switching from analog to digital cable. Some of the European cable companies no longer offer new subscriptions to analog premium channels. The only way of getting new subscriptions to premium channels from these service providers is to get a digital cable box. Today digital cable boxes use about twice as much energy than the analog ones, but it is a relatively new product and as the market matures they will most likely be more energy efficient than today. Only about half of today's analog cable subscribers need a cable box. By switching to digital cable, the number of cable boxes will double, because all subscribers are going to need a digital cable box. Even with a digital TV a cable box is going to be needed. In the worst case, this will increase annual household energy consumption by over 100 kWh per TV set, i.e. increase cable set-top energy use by a factor of eight.

Satellite Service

Satellite services are also in the process of switching from analog to digital. In the U.S. most satellite subscriptions are already on digital satellite services, where about one in ten U.S. homes has a subscription. The number of subscriptions is expected to grow rapidly with the introduction of more interactive services and local TV stations. In Europe, most subscriptions are still on analog services, but many channels have started to broadcast digital over satellite.

Multifunction

There is a good reason to believe that set-top boxes in the future will be multifunction boxes. Because of the similarities of different digital set-top boxes they could easily be built as one single box that receives signals from digital satellite, digital cable, and digital terrestrial. This is shown in Figure 7-1. The differences are how the signals are received and demodulated.

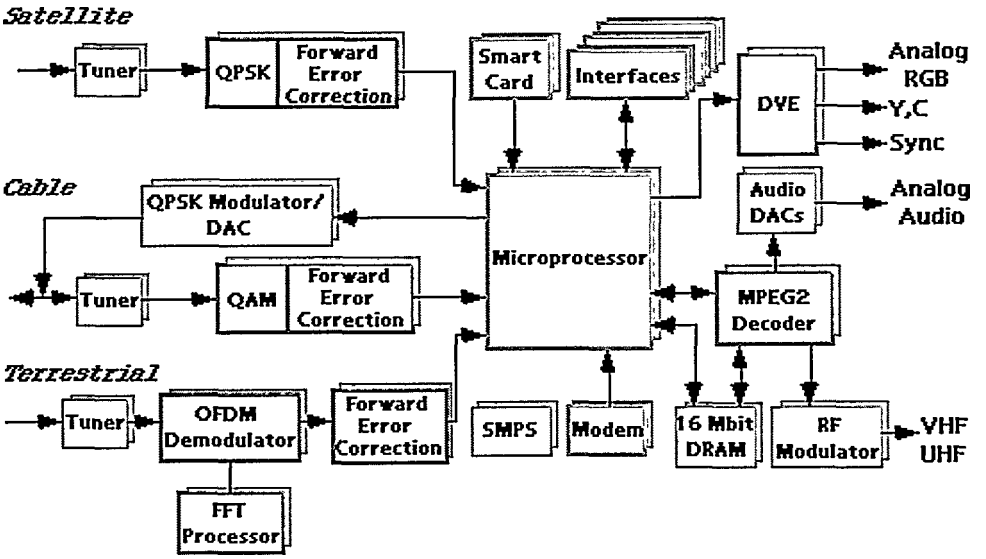

Figure 7-1, Block Diagram, IRD [21]

Telephone, cable, and wireless communications services can now transmit voice, digital video, and data. Many of these functions are currently available in standalone set-top boxes, but soon these and a wide range of other entertainment and

communications services, such as interactive TV and video gaming applications will be incorporated into a single box. In the future, set-tops are expected to evolve into "home hubs" and gateways to the network outside the home. Inside the home, the units will connect all electronic equipment, offering integrated access to audio, video, telephony, and data processing. Such a device might distribute Internet access to the home PC, video on demand to the DTV, and voice service to an IP-based telephone [22]. Some experts also predict that set-tops will offer one-stop control of temperature, lighting and home security systems. Since any networked device would also have access to the Internet through the set-top, it could be used to access Internet applications, or conversely, could be controlled from a remote location through the Internet.

In the worst case scenario, every TV in the future will be accompanied with a set-top box. In the EU there will be about 150 million TVs in the year 2010 [16]. With a set-top box to each of the TVs in the EU, the annual energy consumption of set-top boxes will be approximately 15 TWh by the year 2010. That is if no improvements in energy efficiency are done. That is an increase by 10 TWh or 200% compared to 1999. In the U.S. the annual energy use of set-top boxes is estimated to be nearly 30 TWh by the year 2010 [14]. That is an increase by over 20 TWh compared to the energy use of 1999.

8 Summary

In the U.S., there were over 110 million set-top boxes in 1999. About half of these boxes were game consoles. In the EU, the number of set-top boxes was estimated to be about 71 millions in 1999. The most common set-top boxes in the EU were analog satellite receivers. That is quite a difference from the U.S., where almost no analog satellite receivers exist. It is expected that the amount of set-top boxes will increase rapidly when the broadcasts switch to digital.

Set-top boxes in the U.S. consume 7.9 TWh of electricity every year. Of this 5.5 TWh, or 70 %, are consumed while in standby mode. The amount of energy used in standby in the U.S. would be enough to heat about 220,000 Swedish houses. Even though almost half of the set-top boxes in the U.S. are game consoles, they only use 30 % of the set-top energy. This is because they have low standby power. Since most analog cable boxes have a very high standby power, 46 % of the set-top energy come from analog cable boxes. Analog cable boxes use 76 % of the energy in standby mode. The set-top electricity consumption in the U.S. is 0.70 % of the residential electricity use.

In the EU the total amount of energy used by set-top boxes is 5.1 TWh every year. The fraction used in standby mode in the EU, 60 %, is smaller than in the U.S. In the EU, the most common boxes are the analog satellite receivers. They use 59 % of the total set-top energy, or 3.0 TWh. The set-top energy share of the residential electricity use in the EU is about 0.85 %. Sweden has a share that is less than half of the EU share. One reason for that could be that a lot of electricity is used for heating in Sweden.

In most set-top boxes, high standby power is because most circuitry and components are still powered when they are not in use. By making modest redesigns and changes of communications protocols between the service provider and the user, the energy efficiency could be increased and the standby power consumption reduced significantly.

If nothing is done to decrease the power demand the energy use of set-top boxes will grow dramatically. In the worst case scenario, every TV in the future will be accompanied with a set-top box. With the set-top boxes of today that would mean an annual set-top energy consumption of 15 TWh in the EU and nearly 30 TWh in the U.S. by the year 2010. Today the most power hungry boxes are the new digital set-top boxes. They are likely to be more energy efficient as the market matures.

The EPA is currently working on including set-top boxes in the Energy Star program and the GEA has already some set-top boxes included in the GEA label program. These programs will hopefully help to make future set-top boxes more energy efficient. One of the obstacles in this work will be to convince the manufacturers that it is possible to achieve power levels that are low enough.

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